



Chicago, IL
Aug 16-18, 2016

2016 Resilient Critical Infrastructure Student Competition

The 2016 Resilient Critical Infrastructure Student Competition will take place on Tuesday, August 16.

Part 1: Lightning Talk
1:30-3:30PM

Lightning talks are short presentations that follow a strict format (see below) and are intended to maximize exposure of ideas.

Part 2: Poster Session
3:30-6:00PM

Students will also present their research during a poster session—providing the opportunity for more in-depth discussion about their research in a more relaxed atmosphere.

Lightning Talk Format:

- Each talk will consist of exactly 15 slides that are presented for exactly 30 seconds each. Thus, the total presentation length is 7.5 minutes. Talks will be launched at 10-minute intervals, leaving approximately 2.5 minutes for Q&A and transition between speakers.
- Each presentation will be set up so that slides automatically advance at 30-second intervals. Once the presentation begins there is no pausing or backtracking. Presenters will not have control of how their slides advance.

Schedule of Presentations

Title: Human in the Loop Design and Optimization for Resilient Infrastructure Networks

Authors: Aybike Ulsan*, Northeastern University; Ozlem Ergun, Northeastern University; Casper Hartevelde, Northeastern University; Michael Williams, Northeastern University

Abstract: Due to the increase in the frequency, unpredictability and impact of disruptive events in our society, designing and managing resilient infrastructure networks is of critical importance. However, most of the resiliency problems have a complex nature and hard to solve thus require novel solution methodologies. In this project, we are investigating a unique interdisciplinary approach that combines data driven mathematical modeling with human-in-the-loop game based experiments. Our goal is to find evidence that the complex multi-objective problems modeled to improve resiliency are best optimized by the collaboration of humans and algorithms, and build a decision support tool in order to aid decision making after an external disruptive event. In order to analyze the contribution of human input, we tackle the debris collection problem by modeling it as a mathematical model first and then integrate this into a game. The debris collection problem arises in the aftermath of a disaster and models the decision making process faced by contractors of collecting debris from a transportation network to the disposal facilities. The problem has a multi-objective nature which embodies implementable division of a service region among subcontractors such that the assigned workload among different subcontractors is balanced and the time to complete all debris collection operations is minimized. More specifically, the subcontractors' operating time and the profit gained from all the operations should be similar while functioning on geographically contiguous and distinct regions. Such region assignment prevents conflicts between different subcontractors, it is easier in terms of execution and provides clear responsibilities. The complex multi-objective nature of the problem gives rise to the need for novel solution approaches. In this study, we explore the potential of having humans collaborate with algorithms to achieve better practical solutions in a more efficient manner. We claim that as the human input functions as an external feedback mechanism to the optimization algorithms, the decision making tools based on mathematical models improves drastically. In addition, humans are better in assessing the trade-off

between multiple objectives and when the problem is presented with a visual data, they are competent in finding geographically contiguous and compact regions since they can see the big picture immediately on the contrary of the algorithms that collects individual information to form the big picture. We leveraged game-based simulations in lab experiments to investigate the contribution of humans. To test our conjectures, initially we deployed an Excel-based prototype and collected player decisions and observations in a within-subjects experimental pilot study. While the initial pilot results show that the average player is still relatively worse than the computer, the players have provided many insights into the development process. Much of the player feedback is geared towards understanding how they are tackling the problem and what features the digital version ought to have. The pilot tests explored a variety of networks and set ups, with a variety of difficulty. The ability for the human to influence the solution was relatively stable across all the situations. With the encouraging pilot test results we are currently developing a graphical user interface where the human player can visually assign regions to the contractors. Building on all the experiments, our objective is to create a digital tool which utilizes both human input and optimization algorithms that would enable industry and public service decision makers to be more effective in the design and management of complex infrastructure networks under extreme events.

Title: Urban flooding forecast for Phoenix roadways under increasing precipitation

Authors: Yeowon Kim*, Arizona State University; Emily Bondank, Arizona State University; Mikhail Chester, Arizona State University

Abstract: As US cities continue to grow by altering landscapes and building more civil infrastructure, their roadways are becoming increasingly vulnerable to urban flooding caused by future extreme weather events (i.e., more frequent heavy rainfall). The vast majority of urban growth in the US is asphalt and concrete based “gray infrastructure”, such as roads, buildings and parking lots. This infrastructure increases impervious surfaces and results in a rise in the amount of surface runoff generated. When local drainage structures exceed their capacity to accommodate rainfall through evaporation, infiltration, and surface runoff flow to storm drains, water accumulates on roadways and damages roads, cars, homes, and lives. In general, these urban floods have multiple hydrologic and hydraulic causes that make their modeling and prediction a significant task when planning future roadways and urban development. In particular, climate change research focused on the US Southwest predicts a greater chance of extreme events, including heat waves and flooding. Motivated by this literature and recent major flooding in Phoenix, Arizona in 2014, we combine urban hydrology and climate models to assess how flooding of Phoenix-area roadways may increase due to climate change and where flooding may happen, and opportunities for adaptation strategies. According to Federal Emergency Management Agency (FEMA), there are at least two major types of floods that occur in inland urban areas: 1) floods from riverine stream overflows and 2) floods caused by improper urban drainage unrelated to stream overflow. FEMA reports that “around 20 - 25 percent of all economic losses resulting from flooding occur in areas not designated as being in a ‘floodplain,’ but as a consequence of urban drainage”. In this study, we specifically focuses on floods caused by the failure of urban drainage network infrastructure and their impact to roadways. FEMA states that six inches of water reach the bottom of most passenger cars and cause loss of control. A foot of water floats many vehicles, and two feet of moving water carry away most vehicles, including SUVs and pickup trucks. Thus, we estimate potential flooding locations in the city of Phoenix that will have more than six inches of flooding depth at the event of rainfall by modeling stormwater drainage networks in the city. First, we delineate subcatchments based on elevation information of Phoenix using the hydrology tool of ESRI ArcGIS software. Then, we calculate area, slope, impervious rate and drainage point of each subcatchment to pre-process input parameters for the Environmental Protection Agency (EPA) Storm Water Management Model (SWMM). We assume that storm drain structures (i.e. inlets of the subcatchment) are located at intersections of major roadways. Second, we use EPA SWMM to model

the drainage network to predict flood potentials caused by excessive surface runoff produced by rainfall. We obtain climate change scenarios and their effect on local precipitation and temperature using SWMM-Climate Adjustment Tool (SWMM-CAT) which uses projection results from the EPA's Climate Resilience Evaluation and Analysis Tool (CREAT). To represent the inherent uncertainty in predicting future climate conditions, SWMM-CAT defines three climate scenarios (Hot and dry, Warm and wet, and Median change) in the model for any given projection year. Last, using projected precipitation data obtained from SWMM-CAT, we estimate the flooding volume at each modeled inlet node of drainage network in the SWMM for the near and far future periods (2020-2049 and 2045-2070, respectively). Our flood forecasting results show that among 325 modeled storm drain points, which are potential urban flooding locations, 55 locations are identified as being at the risk of more than six inches of flooding depth by the historical maximum data. Compared to the historical data, in 2020-2049, there will be a 3.6 percentage increase in the number of locations that are flooded above six inches, and in the 2045-2070, there will be 25.5 percentage increase. The latter increase is defined as 14 more location points than the historical data. We claim that the nodes that flooded the most are the ones that have higher imperviousness rate coupled with higher precipitation values compared to the other nodes. We further assess the flooding intensity to the one foot and two feet at each location for three different climate projections. The results show that there will be 400 percentage increase in the number of locations that exceed two feet flooding depth both projection time periods of 2020-2049 and 2045-2070, even in the climate scenario of Median change. Moreover, if we consider regional stream river flooding potentials added to the urban flooding at drain points, the results of this study can be rather conservative, while the consequences of flooding can actually be worse. For example, one potential extreme flooding node is located at the intersection of 91st and Glendale Avenue in Phoenix (Figure 1). Here, stormwater is collected at the drain and flows to the Agua Fria-New River, which is an outlet point of drainage pipelines. As shown in Figure 1, Highway 101 is located less than one mile from the drain point and the river stream. This implies that the road can be affected both urban and stream flooding at the same rainfall event and may cause a major road system failure. Furthermore, it suggests a need for future research on improved urban flood forecasting models coupled with regional flooding models, especially for the drainage networks located in stream floodplain areas. Increases in peak river discharge flow will lead to a reduced capacity for drainage outflow to the stream, which may hold ponded stormwater longer in the flooded area. Our results generate a picture of Phoenix flooding that, if realized, will have a significant impact on local infrastructure beyond roads. In order to assess flooding impacts, multiple climate models, urban drainage, and stream flow models have to be combined together, nonetheless, where the uncertainty of data and results is only amplified as projected data are used across models. Taken together, our results not only demonstrate increased potential for major urban flooding in Phoenix, Arizona due to climate change, but the inherent uncertainty and unpredictability of the climate impacts we assess require a new approach to road infrastructure and urban design. Therefore, we recommend existing design strategies using our and other predictions of climate impacts to implement a new design paradigm, referred to as "safe-to-fail". Traditional infrastructure design approaches focus on creating infrastructure systems robust to future climate risks and protecting them from any form of potential failure ("fail-safe"). As recent extreme weather events and our study results show, however, assessing the potential climate risks faced by urban infrastructures comprehensively is becoming a greater challenge for infrastructure designers and managers. In contrast to fail-safe design, a safe-to-fail approach is to design resilient infrastructure systems that are capable of adapting to the uncertain extreme weather and unpredictable infrastructure failures we expect climate change to cause. Thus, we recommend safe-to-fail design must be included in existing road climate adaptation efforts to enhance infrastructure adaptation capacity to be more dynamic while minimizing impacts from future climate risks.

Title: Automated extraction of dynamic parameters of infrastructure by video motion magnification and unsupervised machine learning

Authors: Charles Dorn*, University of Wisconsin - Madison; Yongchao Yang, Los Alamos National Laboratory; David Mascarenas, Los Alamos National Laboratory

Abstract: Structural dynamic parameters are critical indicators of the state of health of infrastructure, providing essential information for dynamic modeling of infrastructure. Experimentally identifying structural dynamic parameters is thus important for condition assessment and response prediction of infrastructure. Modal analysis is the pivot technique for identifying dynamic parameters of structures. However, traditional modal analysis measurement techniques usually require sensors that are physically attached to the structure of interest. Physical instrumentation of infrastructure is expensive, time-consuming, and requires significant maintenance. As an alternative to traditional modal analysis measurement methods, digital video cameras provide cost-efficient, remote, and high spatial resolution measurements that can be used for modal analysis. This work presents a novel computer vision technique capable of efficiently and autonomously analyzing structural dynamic parameters. Employing unsupervised machine learning approaches alongside phased-based video motion magnification, this method provides a robust platform for modal measurements. Validation through laboratory experiments suggests this method could potentially develop into a versatile city-scale structural health monitoring tool.

Title: A Networks Perspective of Air Traffic Delays

Authors: Karthik Gopalakrishnan*, Massachusetts Institute of Technology; Hamsa Balakrishnan, Massachusetts Institute of Technology; Richard Jordan, MIT Lincoln Laboratory

Abstract: The air transportation system is a critical national infrastructure. It is also a very highly-interconnected system with hundreds of airports and thousands of flights operating every day. The connectivity is enhanced by aircraft flying multiple legs in a day, as well as crew and passenger connections. As a consequence, delays can spread in complex ways, and can potentially lead to system-wide disruptions. Air traffic delays can be represented as a network, where the airports form nodes, and the edges are weighted by the delay level of flights between two airports. This network captures the spatial pattern of delay at any time. In addition, delays also show seasonal, daily, and even hourly trends, resulting in time-varying topologies. Studying these two aspects of delay networks (the spatial structure and the temporal evolution) using operational data is the first step toward identifying critical airports or vulnerabilities in the system. There has been limited prior research on the structure of delay networks. Most related work on air transportation has focused on flight connectivity networks, where central airports for passenger connectivity are identified. These networks can be modeled as undirected networks, because the number of flights between two airports is almost the same in both directions. Delays, on the other hand, tend to be asymmetric between airports, resulting in weighted and directed networks. Furthermore, previous work in clustering has focused only on individual airport delays, and not on the delay network. In this research, we propose a procedure for clustering weighted-directed networks in order to extract characteristic delay modes. We use measures of network interaction- the hub and authority scores, to develop feature vectors for clustering. This approach can be extended to also identify characteristic types of days, based on the progression of delays. At a finer resolution, we identify communities of airports within the network that share common delay features. The community structure shows a strong dependence on the characteristic delay mode of the network. The analysis of the network structure helps identify key airports, and the role they play in delay propagation [1]. The dynamics of delay has typically been modeled using queuing network models, which tend to be data intensive and even computationally intractable for large systems. We propose an alternative, scalable model that leverages the characteristic delay modes previously identified. A switched

linear system model with Markovian transitions between different network topologies is used to model the spreading process. Using the model, two important measures of resilience are evaluated. The first one is the effect of the network on delay dynamics at an airport. Some airports are influenced more by neighbors than others. We provide a quantitative estimate of this network effect and also evaluate the set of ‘influencing airports’ for each ‘influenced airport’. The second metric is the persistence of delays at an airport. Airports with a very small supply-demand margin are shown to have high inertia to changes in delays [2]. In summary, we present an analysis of structural and temporal variation in air traffic delay networks, using models built from real data. We identify and characterize typical delay patterns in the NAS, and use them to model the delay spreading process. Our model can be used for predicting delays, and for analyzing an airport’s vulnerability to disruptions at other airports. A possible extension of this work is the development of control strategies to mitigate the impact of disruptions [3].

References:

- [1] K. Gopalakrishnan, H. Balakrishnan, and R. Jordan, “Clusters and Communities in Air Traffic Delay Networks,” in American Control Conference, July 2016
 - [2] K. Gopalakrishnan, H. Balakrishnan, and R. Jordan, “Stability of Networked Systems with Switching Topologies” submitted to Conference on Decision and Control, December 2016
 - [3] K. Gopalakrishnan, H. Balakrishnan, and R. Jordan, “Deconstructing Delay Dynamics: An air traffic network example,” in International Conference on Research in Air Transportation (ICRAT), 2016
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Title: Toward Mission-centric Vulnerability Analysis for Critical Systems: Methodology and Approach

Authors: Georgios Bakirtzis*, Virginia Commonwealth University; Carl Elks, Virginia Commonwealth University; Peter Beling, University of Virginia

Abstract: This paper presents the process we use to identify potential (i) critical and (ii) vulnerable aspects of a cyber-physical system, which could require further defenses in order to ensure mission dependability. The methodology, called MissionAware Cyber-Security, is contextualized at the highest level by mission requirements (i.e., formal statements of mission phases and needs), the system architecture (i.e., structure and function), and the anticipated attack surface with respect to classes of attacks. The mission requirements are created by key stakeholders, to include owners, operators, and system architects. The system architecture is hierarchically modeled using SysML authoring tools and expresses the information flow between layers and sub-systems as well as metrics of criticality for each sub-system. The attack surface model is developed to relate exposure of the system functions to cyber-attack patterns. Our approach to modeling cyber-attacks is based on the CAPEC library and its corresponding schema, which is used to construct a library of attack patterns. The attack patterns are then used to generate attack chains, which are defined by the attack prerequisites and attack vectors. Finally, we use a genetic algorithm to help search the system architecture attack surface with respect to applied attack chains, for the purpose of uncovering vulnerabilities. Thus, we gain intuition about both criticality and vulnerability. Currently, cyber-vulnerability assessment approaches are mainly at two ends of the spectrum; they are either low level analysis of code and data packets (e.g., Wireshark, Metasploit, IDA Pro) or high level compliance auditing checklists. A systems level approach that bridges the gap between low level analysis and higher level analysis methods is seen as a step toward what we term SystemAware Cyber-Security, which takes a point defense orientation distinguished from the common perimeter (e.g., network, operating system) defenses. Many agree that architecting truly resilient systems that can withstand and recover from attacks is something that can be achieved only by adopting a holistic systems-based approach to the management of cyber risk. In addition, there is little research to be found on methods, theories and tools to assist heterogeneous stakeholders–

cyber- analysts, mission authorities, etc.–in understanding and gauging the risk and impact of various cyber events to systems from mission requirements. We present recent work on a system aware cyber security research project that allows the cyber analyst to gain insight into vulnerabilities of critical system assets from a mission perspective. To date, we have developed a set of interactive toolboxes, built using iPython workflows, that connect iPython with SysML authoring tools. The toolboxes allow automated querying of system information from SysML models, creation of graph structures to represent critical relationships between systems and mission requirements, and calculation of infiltration rates. We have demonstrated the methods and tools on several significant applications, most notably a military Unmanned Aerial Vehicle (UAV) mission. Our approach addresses a significant problem in the analysis of complex cyber-physical systems on three fronts: (i) incorporation of mission perspectives in the cyber-vulnerability analysis process, (ii) development of system level models that can be used to ascertain potential vulnerabilities in systems before they are deployed, and (iii) emphasis on tool assistance and automation to enable exploration of the architecture vulnerabilities through directed search methods.

Title: Algorithm for Probabilistic Modeling of Interdependent Critical Infrastructure Systems

Authors: Chloe Johansen*, Georgia Institute of Technology; Iris Tien, Georgia Institute of Technology

Abstract: Interdependencies between infrastructure networks have been revealed as critical due to aging infrastructure and the possibility of cascading failures. By understanding the relationships both within and between different infrastructure systems, we propose to improve the resilience of these systems by formulating a model that efficiently defines a Bayesian Network (BN) of a community's infrastructure. A BN is a probabilistic graph, which captures dependencies both within systems and between systems. It facilitates uncertainty modeling and allows for the addition of prior and updating information, which propagates through each node in the graph. The BN uses a minimum link set formulation to compress the network complexity. We consider three types of system interdependencies, including service provision, geographic, and access. Service provision interdependencies consider the function of one component depending on the service outputs of another. For geographical interdependency, two or more components in the same geographical area, which are more likely to fail together, are considered. Access interdependency addresses post-disaster recovery and involves the inability to repair failed components because of decreased physical or cyber access, e.g., damaged roads or communication towers. The algorithm uses a connectivity matrix to create a BN modeling the systems and the interdependencies between them by defining minimum link sets and the associated conditional probability tables for the network. Automated detection of the minimum link sets in the network is first performed. The algorithm then uses these minimum link sets to construct the BN and define conditional probability tables that characterize the entire network, including interdependencies within and between different infrastructures. Inference analyses across the BN identify critical components and assess infrastructure resilience across different scenarios. To validate the algorithm, it is applied to an example network of the power, water, and gas distribution systems in Shelby County, Tennessee. The entire network is made up of 125 components – 60 power, 49 water, and 16 gas – and 164 links – 74 power, 72 water, and 18 gas. Each component is a supply station, a substation, or a transshipment station where two or more distribution lines meet. Each link represents a distribution line, i.e., gas or water pipe or power line. The ability of the algorithm to construct a probabilistic BN model of these interdependent systems is demonstrated.

Title: Stress-Strain Capacity Analysis for Robust Infrastructure Service during Post-Disaster Recovery

Authors: Juyeong Choi*, Purdue University; Makarand Hastak, Purdue University

Abstract: This paper introduces the functional stress-strain principle for quantitatively analyzing capacity needs of critical infrastructure in post-disaster scenarios while adopting the concept from material science. To adequately support post-disaster communities, critical infrastructures need to have enough strain capacity in place to accommodate functional stress while remaining within elastic state of stress. The proposed principle facilitates i) systematic understanding of dynamic operation condition of critical infrastructures and ii) identification of the gap in existing and required infrastructure capacities during post-disaster recovery. This will guide the development of operational strategies to accommodate the increased demand of infrastructure services during the post-disaster recovery.

Title: Vulnerability of Urban Water Systems to Climate Change and Mitigating the Potential for Cascading Failures

Authors: Emily Bondank*, Arizona State University; Mikhail Chester, Arizona State University; Benjamin Rudely, Arizona State University

Abstract: As ambient temperatures increase in the Southwest from climate change, the urban water infrastructure designed to operate under historical temperature conditions will become increasingly vulnerable to component and process failures. The increasing frequency of component failures has the potential to decrease the reliability of water supply. A combined mean time to failure and fault tree analysis is used to model the propagation of infrastructural component and process failures to decreases in system-wide performance under future climate conditions, using Arizona water infrastructure as a case study. For each temperature-sensitive component (i.e. motors, pipes) and functional process (i.e. biological growth and chemical reactions) in the infrastructural systems involved in water treatment and transmission, the probability of failure of the is calculated for a range of possible ambient temperatures. The probability distributions of component and process failure are characterized by performing Monte Carlo simulations on ranges of input characteristics that are used in lifespan derating and process equations to calculate the mean or random variable of probability distributions. Integration under the probability curves for a period of a year using the failure rate method yields the yearly probability of component or process failure. Systemic probabilities of water outage from pump station outage, water main break, and water quality failure, are calculated by propagating component probabilities of failure through fault-tree logic. In a future where average summertime temperatures have increased from 40oC to 45oC, there could be up to a 23% increase in any systemic failure mode occurring, which changes opportunity of failure from around 500 times per year to 600 times per year. There could be an even greater increase in probability of all failure modes occurring simultaneously, at 96% increase, which changes opportunity of failure from around 70 times per year to 550 times a year. At a component level the number of pipe breaks dominates the overall absolute and percent increase in any type of systemic failure. Pumping stations, electronics, and motors see the most percent increase in annual expected component failures, however. The most sensitive components to failure from increasing temperatures at different operating characteristics are pumping stations and chlorine disinfectant. The operation of electronics and motors inside pumping stations significantly contribute to their operating temperatures and how much ambient temperature will affect them. Chlorine decay is very sensitive to the initial chlorine concentration and the water age within the system. Conversely, the expected value of pipe failures is not very sensitive to changes in characteristics like pipe diameter and operating pressure and thus could not be easily curbed through changing these characteristics. To mitigate risk of failure of the most sensitive components, pumping station outages and chlorine decay, temperature loading on motors and electronics should be reduced through use of fans or air conditioning. To mitigate the risk of chlorine decay,

chlorine dosage should be increased, and water age in the system should be decreased through circulating water in tanks or flushing the system frequently, or through creating more loops in the pipe network. To reduce the high number of pipe breaks, corrosion inhibitors could be introduced into the system, but should not be the first priority since pipe breaks are not very sensitive to the increase in corrosion from temperature increase. Additionally, to prevent systemic failures from cascading even further to larger areas or durations of failure, preparations should be made to handle multiple failures occurring at once, especially failures occurring with water main breaks. This means that there should be sufficient operators on hand and they should know how to operate the valves to handle all three failure modes occurring in the same time period.

Title: Interdiction Analysis of a Coupled Electricity and Gas Network

Authors: Bowen Hua*, University of Texas at Austin; Ross Baldick, University of Texas at Austin

Abstract: We present an attacker-defender model to identify the critical components of a coupled power and natural gas pipeline system in which fuel supply of some power plants is dependent on the gas network. In the lower-level operator's model, we use a linearized power flow model to describe the power system. We consider nonlinear flow-pressure relationship in the natural gas pipeline network and piecewise linearize this relationship. We solve the interdiction problem with a decomposition algorithm.

Title: Simulating Failure for Student Success

Authors: Lauren McBurnett*, Arizona State University; Madeline Sawyer, Arizona State University; Thomas Seager, Arizona State University

Abstract: Simulating Failure for Building Student Resilience: The LA Water Game - An Innovative Approach to Address the Critical Infrastructure Crisis Lauren R. McBurnett, Madeline Sawyer, and Thomas P. Seager
Abstract Existing education programs are inadequate for training the workforce required to maintain our infrastructure systems. Since 1998, the American Society of Civil Engineers (ASCE) has regularly reported that infrastructure systems in the United States are in a state of continuous crisis (ASCE 2013). As an indication of the severe need for improved infrastructure the National Academy of Engineering has listed "restore and improve urban infrastructure" and "provide access to clean water" among the Grand Challenges for Engineering in the 21st Century (NAE 2008). Presidential Policy Directive (PPD-21) addressed the need "to strengthen the security and resilience of its critical infrastructure against both physical and cyber threats." These and numerous other reports articulate the need for resilient and sustainable infrastructure systems. However, current educational programs do not prepare students with the systems thinking and complex reasoning skills to understand the challenges presented by 21st Century infrastructure crisis. Simulation platforms will provide the additional training strategies that are critical for preparing a workforce capable of addressing the presidential mandate and redirecting the future of the infrastructure crisis. Modern infrastructure is an aggregation of complex systems. The interactions between food, water, and power systems show an increasingly high degree of connectivity. Sustaining modern infrastructure requires additional energy and innovative technologies. As is the case with complex systems, these infrastructure systems are inseparable and their impact on the whole of society is vast and innumerable. The behavior of infrastructural systems is in nonlinear, exhibiting disproportionality between cause and effect relationships and emergent societal properties. Explaining these power-water-food systems using separated, individual representative models requires the introduction of arbitrary system boundaries that differ from the accurate depiction of the real interrelatedness of the systems. However, this abstract conceptualization of

oversimplified infrastructure systems is the status quo of engineering education. Furthermore, undergraduate infrastructural engineering education is sub-divided into disciplines each responsible for a slice (need different word to say hydro systems, power, environmental, structural, geotechnical...etc) critical infrastructure without regard to the overlapping, complex nature of infrastructure systems. Given this non-adaptive, oversimplified approach to engineering education in the midst of an ever more complex world, it should come as no surprise that modern infrastructure is in a state of crisis. To address this critical need, engineering education must adopt simulation-based learning tools that will provide engineering students with experiential and reflective engagement opportunities. Integrating Buzz Holling's "safe-fail" experimental approach through a simulation platform will develop students' complex systems thinking skills and enhance student capacity for resilient critical infrastructure problem solving. Engineering students are commonly asked to produce and utilize mathematical models in order to optimize design parameters for efficiency. Optimization is a valuable skill. However, when students are handed pre-formulated problems and decisive solutions, students develop reductionist patterns of thinking and problem solving. The over-simplified experimental methods fail to reveal truths about the complex, post-industrial society. Traditional engineering pedagogy focuses predominantly on cognitive outcomes, utilizing abstraction and experimentation. (The well-established Kolb learning cycle illustrates how people learn and make meaning of new information - abstract conceptualization, active experimentation, concrete experience, and reflective observation.) Whereas these two elements are essential phases in how people learn, without the other phases of the Kolb learning cycle (experience and reflection) student development in non-transformation. Experience and reflection exercises take the student beyond the just the cognitive level, and facilitate conative and affective learning outcomes. The transformational approach engages the entire Kolb learning cycle, and causes students examine the role of values, ethics, and morals in their professional behavior. The LA Water Game Simulation was designed to improve the learning and knowledge transfer of students. The game develops complex systems thinking skill for the student who interact with the simulation with the intentional use of addressing a modern infrastructure crisis. The LA Water Game asks students to take on the role of the LA City Water Manager and are tasked with maintaining the LA water distribution without getting fired. Student witness how system maintenance, public funding, and public opinion are all interrelated. The game includes as generational component as the system degrades over time, the system is passed from one LA Water manager to the next. With the use of the LA Water Game simulation platform, there are two expected benefits. 1. Improved understanding of complex infrastructure systems, including their interdependencies and multi-temporal feedback loops. 2. Creates opportunities for salient emotional experiences which 3. Motivate actionable decision making. Simulation can induce action prior to disaster, rather than afterwards (as has been characteristic of major disasters). The LA Water Game simulation platform creates experiences for teams to interact in a realistic, immersive environment. The simulation is integrated in a larger curriculum to facilitate the desired learning outcomes. Through the LA Water Game simulation platform core competencies, the simulations will be replicable and scalable.

Title: Bridging sociotechnical networks for critical infrastructure resilience: South Korean Case Study

Authors: Daniel Eisenberg*, Arizona State University; Thomas Seager, Arizona State University; Jeryang Park, Hongik University

Abstract: There is a growing recognition that critical infrastructure systems (CISs) depend on the functionality of technical components and the actions taken by people to plan and prepare for, absorb, recover from, and to adapt to unforeseen events. The majority of empirical work, however, analyzes CISs isolated from their social context, or vice versa, limiting the practicality of derived conclusions. It is necessary to develop analysis methods that bridge social and technical data to situate CISs in their real-world context and develop concrete technical, operational, tactical, and policy recommendations. Network science has emerged as one approach



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to model the components and interactions in CISs, and has seen extensive use across relevant social and technical systems. However, the disparate nature of the nodes, links, and flows within social and technical networks limit the feasibility of combining systems into a single sociotechnical analysis. In our work, we seek to answer a single question: how should corresponding social and technical networks be combined to study critical infrastructure resilience? Here, we study crisis management networks for the organizations charged with managing electric power crises in South Korea (Korea hereafter) and how to relate them to a corresponding Korean electric power grid network. First, we use betweenness to assess how organizations influence crisis management. Betweenness is a measure of the flow contribution of any network element, and is essential for studying information sharing and crisis coordination in interorganizational networks. Still, multiple formulations of betweenness exist, ranging from abstract versions that include no annotated data, to those that consider relevant hierarchies, roles, and availability of resources among organizations. We use three formulations of betweenness to rank nodes and links in a South Korean electricity crisis management network, and demonstrate that network representations that ignore annotated crisis management data are unsuitable for resilience assessment. Second, we develop a method of studying time-varying sub-networks of the Korean interorganizational system that form based on dynamics occurring within the Korean electric power grid. In particular, we implement cascading failure models in a Korean power system network and relate the size, location, and duration of cascades to relevant electric power crisis management organizations. We run the cascading failure models for numerous technical failure scenarios and assess the resulting social networks as an ensemble to better understand which Korean organizations are most impacted by blackouts. Finally, we combine the first and second parts together to assess the betweenness of resulting social network ensembles to better measure organizational contribution to information sharing and crisis coordination. Results show that Korean power companies across sectors (i.e., thermoelectric, hydroelectric, and nuclear power) receive equivalent treatment in crisis management protocols, yet are affected by blackouts in markedly different ways. Moreover, the five major thermoelectric power companies contribute equivalently to national power generation (~10% of total capacity), yet individual companies like Korean Southeast Power are involved in a greater number of cascading failures. The comparison between static analysis and time-varying ensemble analysis indicates that the betweenness of organizations shifts dramatically depending on the size, location, and duration of technical failures. In particular, static analysis characterizes crisis management agencies such as the Korean National Emergency Management Agency and the Ministry of Security and Public Administration as having the greatest influence on information sharing and coordination for certain blackout scenarios. On the other hand, ensemble analysis of time-variant analysis weighs organizations within the power system – the Korea Power Exchange and the Ministry of Trade, Infrastructure, and Energy – as always having the greatest contribution on crisis coordination. Taken together, this work generates a new understanding of how blackouts influence interactions among Korean organizations and is a first step towards integrated sociotechnical CIS resilience analysis.